

## Chapter 3

# Bioprocessing Requirements for Bioethanol: Sugarcane vs. Sugarcane Bagasse

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### ABSTRACT

*This chapter discusses alternative energy sources and the advantages of biofuels over fossil fuels. It outlines the main steps of bioethanol production and suggests some alternative sources as potential feedstock. The core focus of this chapter is to examine new research which considers the use of agricultural waste as a feedstock for bioethanol production rather than conventional feedstocks such as sugarcane and corn. The advantages of sugarcane bagasse as a feedstock are discussed in detail and the bioprocessing requirements are studied in comparison to traditional methods that use sugarcane as the feedstock. The chapter concludes by briefly outlining further research that could potentially improve these processes.*

### INTRODUCTION

The world demand for energy and the depletion of oil reserves motivates the research for alternative energy sources. Biofuels can be defined as solid, liquid or gaseous fuels predominantly produced from biomass. There is a large amount of interest regarding biofuels due to the advantages over fossil fuels; biofuels are easily accessible from common biomass sources, they have a potential to be more environmentally friendly, there are benefits to the environment, economy and consumers in using biofuels and they are biodegradable and sustainable (Demirbas, 2008). Biofuels are claimed to have a lower 'carbon footprint' than fossil fuels and they contribute less to the greenhouse effect due to the CO<sub>2</sub> neutral conversion owing to the renewability of biomass. However, biofuels do not come without concerns and it is a worry that biofuel crops are replacing food crops. This has adverse implications on food security, especially in poor countries (Vassilev et al., 2015).

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### ***Bioprocessing Requirements for Bioethanol***

Ethanol is one of the most widely used liquid biofuels for vehicles and so is one of the most produced biofuels worldwide. The need for bioethanol is increasing due to depletion of crude oil supplies and the need for a sustainable fuel alternative (Sarkar et al., 2012). The largest producers of ethanol are the United States and Brazil, together producing 85% of the world's ethanol (Alternative Fuels Data Center, 2016). The vast majority of U.S. ethanol is produced from the starch from corn, while Brazil primarily uses sugarcane. However, these conventional crops are unable to meet the global demand of bioethanol production due to their primary value of food and feed. New research is considering the use of agricultural waste as a feedstock for bioethanol production. It is claimed that it is a cost effective, renewable and abundant alternative and it avoids the 'food vs. fuel' argument. A study by Kim and Dale (2004) estimated that 491 billion litres of bioethanol could be produced per year using agricultural waste – 16 times higher than the actual world bioethanol production at that time. Conventional raw materials such as corn or sugarcane contribute to 40-70% of production costs, so by using waste products the cost of feedstock could be reduced (Cardona et al., 2010). The following discussion will study and analyse two different methods of bioethanol production: (1) sugarcane as feedstock and (2) sugarcane bagasse (waste) as feedstock. The study will discuss the similarities and differences of production and if using waste as a feedstock is beneficial.

## **BIOETHANOL PRODUCTION**

### **Sources and Applications**

The main sources of biomass to produce bioethanol are conventionally sugarcane and corn feedstock, but as discussed above, these sources are barely sufficient to meet the demand (Vohra et al., 2014). Lignocellulosic biomass, also known as agrowaste, is a non-food alternative to this. The possible sources include crop residues, grasses, sawdust and woodchips. More recent research has also explored other possible feedstocks – Byadgi and Kalburgi (2016) considered the use of waste newspapers due to lower feedstock costs and to minimise the newspaper load on municipal waste. Others include bioethanol production from waste potatoes and waste money bills (Sheikh et al., 2013; Ali & Jiyad, 2015)

However, there are four major sources of agrowaste that are widely studied and are most favourable due to their abundant availability. These sources are rice straw, wheat straw, corn straw and bagasse (the dry pulpy residue left after the extraction of juice from sugar cane). As well as the production of bioethanol, a small amount of these feedstocks are also used for animal feed and bedding or fuel for heating and electricity (Sarkar et al., 2012).

*Table 1. Worldwide potential bioethanol production from agricultural wastes*

Agrowaste	Potential Bioethanol Production (Billion Litres Annually)
Rice straw	205
Wheat Straw	104
Corn Straw	58.6
Sugarcane bagasse	51.3

(Sarkar et al., 2012)

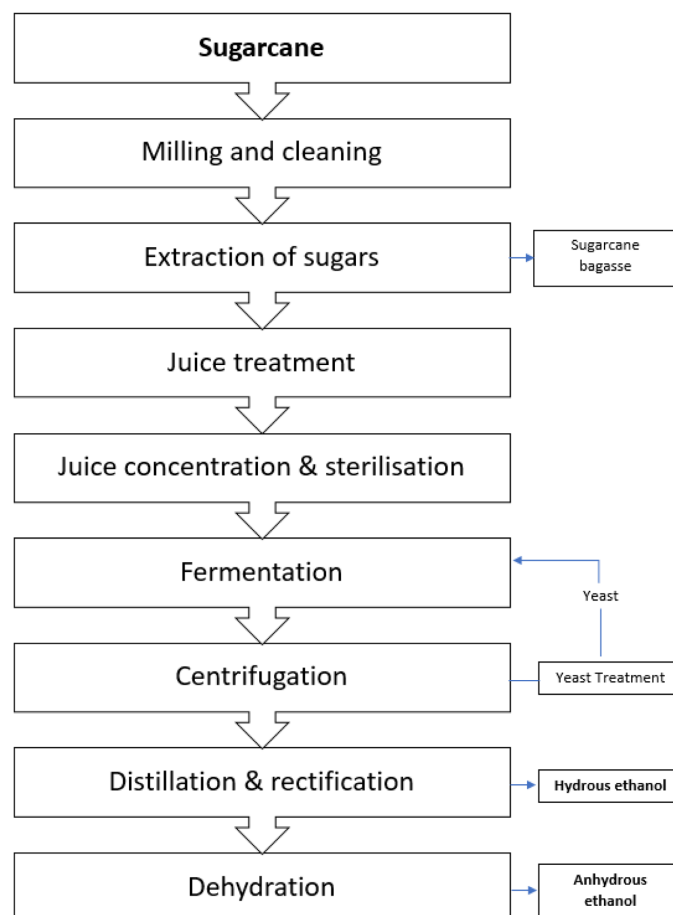
**Bioprocessing Requirements for Bioethanol****Sugarcane as a Feedstock**

The process of bioethanol production depends on the materials used. There are commonly three major steps in its production: (1) extraction of fermentable sugars, (2) conversion of sugars into ethanol by fermentation and (3) separation and purification of ethanol usually by distillation and dehydration (Vohra et al., 2014). The steps prior to fermentation to obtain the fermentable sugars, are the main difference between conventional ethanol production from corn or sugarcane and ethanol production from agrowaste. Figure 1 outlines the main processes for the production of bioethanol from sugarcane.

**Cleaning of Sugarcane, Extraction of Sugars and Juice Treatment**

Sugarcane is harvested from fields. The stalks contain most of the sugars so are most desirable for industry. A dry-cleaning system is used to remove ~70% of dirt which is dragged along from harvesting. The extraction of the fermentable sugars is carried out by mills. Water is used to maximize sugar recovery (~96%) by a process called imbibition. Sugarcane juice and bagasse are obtained from the mills at this stage. In a study carried out by Dias et al. (2009) the recovery of sugars is ~96%. The bagasse

*Figure 1. Process flow diagram of bioethanol product from sugarcane*



### **Bioprocessing Requirements for Bioethanol**

produced here can be burnt for the generation of steam and energy or it can be used as a raw material for bioethanol production.

The sugarcane juice contains impurities that need to be removed for efficient use as a raw material. Hydrocyclone removes physical dirt particles, phosphoric acid is added to enhance impurity removal and increase phosphate content. The juice is then initially heated to 30-70°C and then a secondary heated at 105°C.

### **Juice Concentration and Sterilisation**

The juice must then be concentrated prior to fermentation and this is carried out by a five-stage multiple effector evaporator (MEE). Table 2 shows the pressure and temperature stages of juice concentration and sterilisation.

### **Fermentation**

Yeast suspension (*Saccharomyces cerevisiae*) is added to the fermentation reactor along with the sterilized juice. Yeast is a facultative anaerobe. In an aerobic environment, it converts sugars into CO<sub>2</sub> and water whereas in an anaerobic environment, it converts sugars into CO<sub>2</sub> and ethanol. So for ethanol production anaerobic conditions are necessary. Optimal conditions are temperature of 28°C and pH 4.5 (Dias et al., 2009). Asif et al. (2015) used similar parameters i.e. temperature 30°C and pH 4.6 using *S. cerevisiae*. In contrast, Wong and Sanggari (2014) stated that the optimum temperature from their findings was 35°C but with the same pH of 4.5. Most of these studies used a batch fermentation method with a known amount of yeast suspension and juice.

During fermentation, sucrose is hydrolysed into fructose and glucose which are converted into ethanol and CO<sub>2</sub> (wine and gases). Gases are collected through a column to recover evaporated ethanol and wine is centrifuged to recover and recycle yeast cells. The centrifuged wine is then fed to the distillation unit.

### **Distillation and Dehydration**

The bioethanol from fermentation requires further separation and purification of ethanol from water (Limayem & Rick, 2012). Distillation is used to produce hydrous ethanol using a series of distillation and rectification columns operating under atmospheric pressure. It is the most recognized technique of purifying ethanol. The basic principle is that the wine from the fermenter is heated and the components

*Table 2. Pressure and temperature on each stage of MEE.*

Stage	Pressure (kPa)	Temperature (°C)
1	169.6	115.5
2	135.4	108.8
3	101.0	100.6
4	52.9	83.6
5	20.0	64.6

Data from Dias et al. (2009)

## Bioprocessing Requirements for Bioethanol

with a low boiling point vaporises. These vapours are then condensed to obtain more concentrated, less volatile products in the form of a liquid. So, ethanol and water are separated using these columns. To produce anhydrous ethanol, an extractive separation process is used involving two columns; extractive column and recovery column. Hydrated ethanol vapours are added to the extraction column along with a suitable solvent and anhydrous ethanol is obtained from the top and the solvent solution exits at the bottom. The recovery column is needed to produce a pure solvent that can be recycled back in to the extractive column. (Dias et al., 2011). The columns operate at high temperatures and pressures. Figure 2 shows a schematic of the distillation and dehydration columns (although the extraction and recovery columns are not shown here).

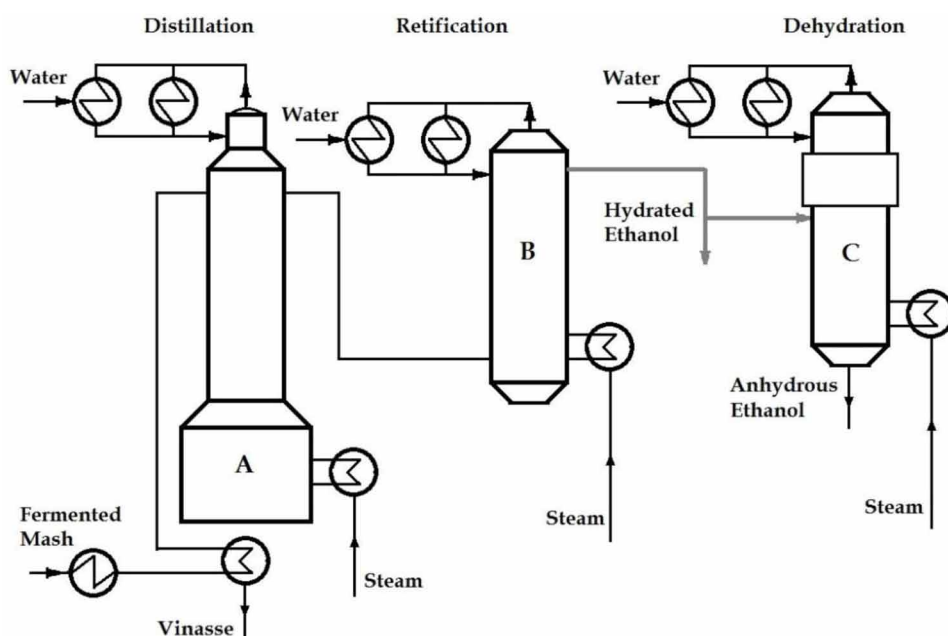
### Typical Yield

Anhydrous ethanol has a purity of ~99.5% compared to hydrated ethanol which is between 93.8 – 93.5 wt.% ethanol. Both types can be used as a fuel source. However, only anhydrous ethanol is used when combined with fossil fuels. The study carried out by Dias et al. (2009) obtained a total yield of 102.5L of anhydrous ethanol per tonne of sugarcane. That included 83.7 (L/t) from sugarcane and 18.8 (L/t) from bagasse.

### Sugarcane Bagasse as a Feedstock

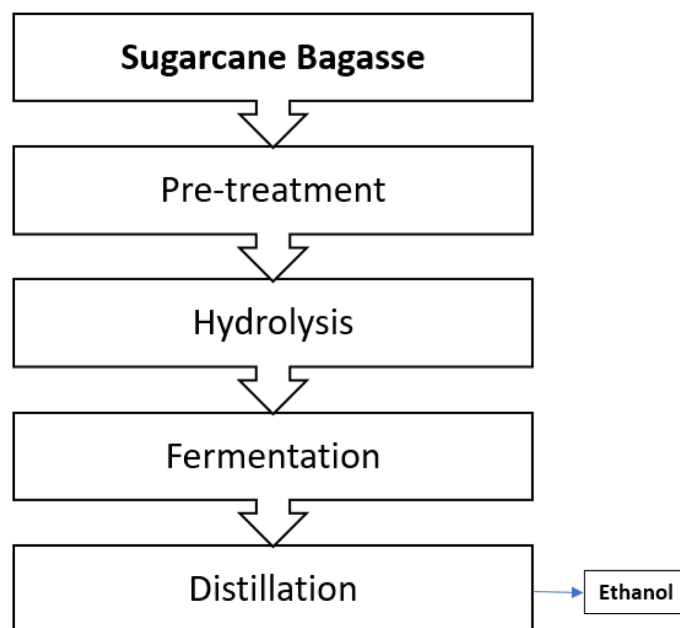
The process of producing bioethanol from bagasse has some major differences. Figure 3 outlines the main methods involved. Lignocellulosic materials like sugarcane bagasse are mainly composed of cellulose, hemicellulose and lignin. The conversion of these materials into bioethanol or other biofuels is

Figure 2. Distillation and dehydration columns (Campo, 2012)



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Figure 3. Process flow diagram of bioethanol production from sugarcane bagasse (Limayem & Ricke, 2012)



complex and needs pre-treatment and hydrolysis stages to increase the efficiency of the product (Eberhard et al., 2017).

**Pre-Treatment and Hydrolysis**

This process differs in that pre-treatment methods are needed to break down lignocellulosic biomass into its three main components; hemicellulose, lignin and cellulose. By breaking these down, it makes the remaining solid biomass more accessible for further treatment i.e. the next step of hydrolysis (Sarkar et al., 2012). This step is fundamental for successful hydrolysis and downstream processes. Unfortunately, these pre-treatment steps are the most expensive part of the process.

The major pre-treatment methods are classified as physical, chemical or biological. Physical methods include mechanical size reduction (such as milling), steam treatment and hydro-thermolysis. For chemical methods, acid/alkali is added to the bagasse to remove lignin, which increases the surface area and makes the material more suitable for fermentation. For biological methods, fungi can be used to enzymatically delignify the material. Table 3 outlines some advantages and disadvantages of these methods.

The next step is hydrolysis to convert the separated cellulose to sugar monomers for the fermentation to bioethanol. This process can be acidic or enzymatic. Enzymatic hydrolysis can be carried out using enzymes from certain fungi. Talebnia et al. (2010) suggested the use of *Trichoderma reesei* or *Aspergillus niger*. Acidic hydrolysis can be subdivided into dilute or concentrated hydrolysis. Concentrated hydrolysis is the preferred method as it isn't followed by high concentrations of inhibitors and produces a large yield of sugars. Unfortunately, it requires large amounts of acid and is an expensive process so it is less attractive commercially (Limayem & Ricke, 2012).

**Bioprocessing Requirements for Bioethanol***Table 3. Advantages and disadvantages of pre-treatment methods*

Method	Process	Advantages	Disadvantages
Physical	Milling	<ul style="list-style-type: none"> <li>• Increases accessible surface area of material</li> <li>• Decreases cellulose crystallinity</li> <li>• Highly efficient method</li> </ul>	High energy demand
Chemical	Acid/Alkali	<ul style="list-style-type: none"> <li>• Increases accessible surface area of material</li> <li>• Decreases cellulose crystallinity</li> <li>• Delignifies</li> <li>• Hydrolysis of hemicellulose</li> <li>• Most effective process</li> <li>• Rapid rate of treatment</li> </ul>	Some methods can generate toxic inhibitors
Biological	Fungi	<ul style="list-style-type: none"> <li>• Delignifies</li> <li>• Partial hydrolysis of hemicellulose</li> <li>• Low energy requirement</li> </ul>	<ul style="list-style-type: none"> <li>• Very low rate of treatment</li> <li>• Unsure on quality for industrial use</li> </ul>

(Limayem &amp; Ricke 2012; Eberhard et al., 2017)

**Fermentation and Downstream Process**

Once the sugar substrates from hydrolysis are available for fermentation, these next steps of fermentation and distillation/separation are the same as the methods discussed above for sugarcane.

The industrial potential for *S. cerevisiae* fermentation has already been proven and its capability is utilised in the industry. Despite its advantages, *S. cerevisiae* is not able to ferment sugars other than hexose. Unfortunately, lignocellulosic material such as bagasse contains mainly pentose sugars so new research is interested in developing genetically engineered microorganisms capable of fermenting hexose and pentose sugars simultaneously. The genetic improvement of the conventional *S. cerevisia* strain is gaining increasing research interest since this strain is already the most optimally adapted to bioethanol fermentation conditions (Limayem & Ricke, 2012).

**FUTURE RESEARCH DIRECTIONS**

Further research to improve these processes of producing bioethanol involve the genetic improvement of the conventional *S. cerevisiae* to be able to ferment both sugar types. There are already a wide range of bacteria able to ferment these sugars but they are not all capable of working under the fermentation conditions and result in low ethanol yields. If research uncovers a way to resolve these issues, the use of lignocellulosic biomass could be an attractive alternative to the use of non-renewable, polluting fossil fuels for fuel.

**CONCLUSION**

The main advantages of the use of waste materials are overcoming the problem of greenhouse gases, the renewability of feedstock, economic benefits including more employment opportunities and to sustain global transport systems (Eberhard et al., 2017).

## Bioprocessing Requirements for Bioethanol

As the world demand for energy alternatives continues to increase, lignocellulosic material/waste seems a viable possibility as a renewable feedstock for the production of biofuels. Despite advances in research, the process of producing this from waste is still expensive and challenging. The availability of these materials is still an issue although studies by Kim and Dale (2004) concluded that sugarcane bagasse is an attractive feedstock due to its abundant available. A significant barrier is the cost of the pre-treatment process which is estimated to account for ~33% of the total cost of production from lignocellulosic material (Talebnia et al., 2010). Until a cost-effective method is discovered, the cost of bioethanol will be high.

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**KEY TERMS AND DEFINITIONS**

**Agrowaste:** Also known as agricultural waste, is waste produced from agricultural operations.

**Bagasse:** The dry pulpy residue waste from the extraction of juice from sugar cane.

**Biofuels:** Fuels produced directly from biomass.

**Biomass:** Renewable organic matter such as agricultural crops or waste, often used for fuel.

**Carbon Footprint:** The amount of carbon dioxide released into the atmosphere because of human activity.

**Feedstock:** Raw material to supply or fuel a machine or process (such as fermentation).

**Fermentation:** The chemical breakdown of a substance by bacteria, yeasts, or other microorganisms.